Chapter 6. Outputs of R&D

While it is difficult to accurately measure the returns to a nation's R&D investment, new knowledge resulting from R&D is sometimes identifiable by discrete events, which can be used as measures of the *output* of R&D activity. Bibliometrics (scientific publications and their citation by other researchers) and patents are two such *output* indicators. Scientific publications reflect research of significance to the scholarly community while patent registrations reflect inventive activity of potential commercial consequence.

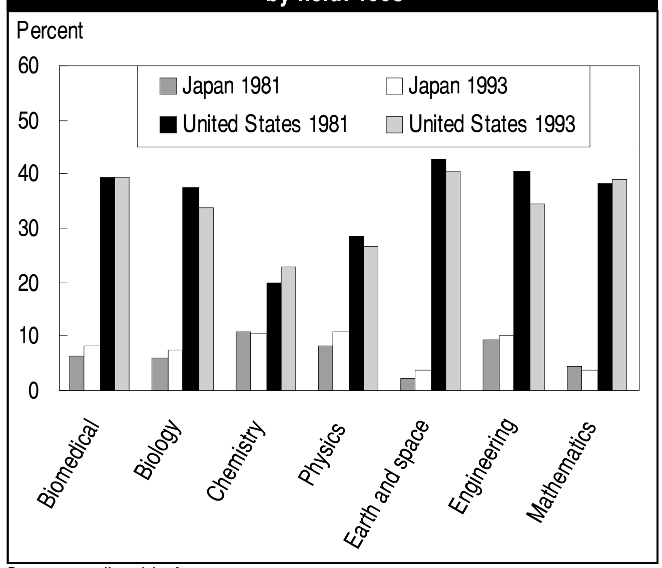
The *impact* of new knowledge resulting from R&D is even more difficult to measure, especially with regard to basic research. R&D would, however, be expected to have an impact on such economic factors as productivity, demand for technological know-how, and international trade. These factors are, in turn, quantifiable in the form of manufacturing output, royalties and fees paid to firms to gain access to technological know-how, and trade surpluses from trade in advanced technology products. These can be used as rough measures of the impact of a nation's R&D efforts.

Scientific Literature

The database used here to compare U.S. and Japanese scientific literature consists of scientific and engineering articles published in the set of 4,681 natural science and engineering journals covered by the Institute of Science Information's (ISI) Science Citation Index (SCI).[24] SCI covers major refereed scientific and technical (S&T) journals from around the world (NSB, 1996). This database is biased toward the English language so it does not reflect all of Japan's S&T literature. Rather, it is reflective of Japan's proportion of articles in this set of globally influential S&T journals.

Japan's share of the world's scientific and technical articles increased somewhat from 6.6 percent in 1981 to 8.8 percent in 1993, based on larger shares of publications across several fields, including clinical medicine, biomedical research, biology, physics, and engineering. Only in chemistry and mathematics has Japan's share of the world's scientific articles decreased from 1981–93 (figure 29). Japanese research papers in material science, agriculture, and astrophysics are frequently cited by other researchers—a clear indication of the quality of Japan's research in these fields (NISTEP, 1995).

Figure 29. Share of world's scientific articles, by field: 1993



See appendix table A-23.

In contrast, as other countries have increased their production of scientific publications, the U.S. share of the world's scientific articles has decreased from 35.9 percent in 1981 to 33.6 percent in 1993. As scientific knowledge is diffused throughout the world and civilian research budgets in the European and Asian regions are becoming comparable to that of the United States (each region reached $100 billion in 1992), a greater share of the world's scientific literature originates in laboratories outside the United States (NSF, 1993 and NSF, 1996c).

[24] The database encompasses the natural sciences and engineering. The social and behavioral sciences tend to rely more on publication vehicles not covered by ISI (e.g., books and monographs). For this reason, these fields are omitted from the database. The database also excludes letters to the editor, news pieces, editorials, and other content whose central purpose is not the presentation or discussion of scientific data, theory, methods, apparatus, or experiments. ISI periodically updates its journal coverage, based in part on references in covered publications to others not yet included. Given this citation-based updating, one can conclude that ISI provides reasonably good coverage of a core set of scientific journals (albeit with some English language bias), but not necessarily of all that my be of local or regional importance.

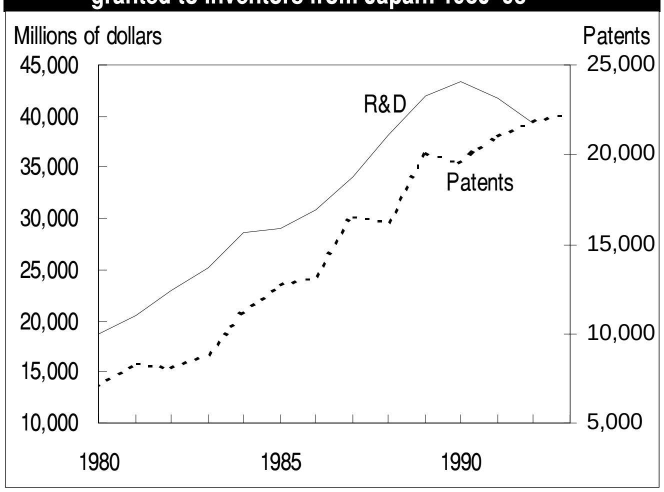
Japan's goal of increasing its international cooperative research, as stated in S&T White Papers since the mid-1980s, has resulted in increased international coauthorship. In the 1988–93 period, almost 11 percent of Japan's scientific articles in this set of journals were internationally coauthored, up from 7 percent in the previous period of 1981–87. While U.S. scientists are still the main collaborators on internationally coauthored articles with Japanese scientists (43 percent), an increasing percentage of these articles are based on collaborations with scientists from European (34 percent) and Pacific Rim (14 percent) countries, particularly China (NSB, 1996).

PATENTS

Patents are one output indicator, albeit partial and imperfect, of the growth in new products and processes that result from industrial R&D. U.S. patents can be viewed as an indicator of global patenting. The analysis of U.S. patenting activity which follows has the advantage of comparing patenting across countries within a patent system requiring the same criterion of invention for patent application.

Japan's investment in industrially funded R&D mirrors the number of U.S. patents granted to Japanese inventors over the last 13 years. (See figure 30.) The very strong growth in industrial R&D throughout the 1980s corresponds with similar strong increases in the number of patents during the same period. From 1980–90, the number of U.S. patents granted to Japanese scientists and engineers increased at an average annual rate of 10.6 percent, from 7,000 in 1980 to 19,524 in 1990. As Japanese industrial R&D funding declined in the early 1990s, the growth rate of the number of U.S. patents also declined, to 2.9 percent annually. Despite this recent slowing in patent growth rate, Japanese inventors still received about 23 percent of all U.S. patents in 1993 and represented almost one-half of all foreign patents granted in the United States, indicating a strong level of inventiveness (NSB, 1996).

Figure 30. Industrially funded R&D and U.S. patents granted to inventors from Japan: 1980–93



See appendix tables A-10 and A-24.

Japanese patenting activity in the United States has been particularly strong in the fields of computers, radio and television, electrical components and communications equipment, and motor vehicles and equipment. In each of these areas, the number of patents granted to Japanese inventors within the U.S. patent system has exceeded the number granted to inventors from all the countries of the European Economic Community (EEC) combined (NSB, 1996). By 1993, several Japanese firms were among the 10 top patenting corporations in the United States (table 13).

Table 13. Top patenting corporations: 1993

Company	Number of patents
IBM Corporation	1,085
Toshiba Corporation	1,040
Canon Kabushiki Kaisha	1,038
Eastman Kodak Company	1,007
General Electric Corporation	932
Mitsubishi Denki Kabushiki Kaisha	926
Hitaschi, Ltd	912
Motorola Incorporated	729
Matsushita Electric Industrial Company, Ltd.	713
Fuji Photo Film Coi, Ltd.	632

SOURCE: National Science Board, *Science and Engineering Indicators: 1996* (Washington, D.C.: U.S. Government Printing Office, 1996).

An examination of domestic patenting trends in Japan also shows the surge of applications from industrial researchers in the 1980s and a leveling off in the number of applications in the 1990s. In 1993, applications from Japanese inventors to the Japan Patent Agency declined (NISTEP, 1995). The number of patents granted to U.S. inventors also grew throughout the 1980s, at 2.4 percent annually, and even more slowly in the 1990s, at 2.0 percent annually.

Industrial Productivity

Recent assessments of Japanese technology have observed that one of Japan's strengths has been in applying technology to production processes. In industrial manufacturing fields that involve both complex products and processes, Japan excels and achieves a large international trade surplus (Kash, 1996). Japan has also made rapid progress in manufacturing productivity during the past decade; manufacturing output per worker-hour increased 4.3 percent annually from 1984–94, compared with a 2.9-percent annual increase in the United States in the same period (table A-25).

Table 14. U.S. receipts of royalties and license fees from Japan: various years 1/

Factor	1987	1990	1993
	[Millions of current dollars]		
Receipts	$723	$1,028	$1,392
Payments	88	141	194
Balance	635	887	1,198
Ratio of receipts to payments	8:1	7:1	7:1

1/ Generated from the exchange and use of industrial processes with unaffiliated foreign residents.

SOURCE: National Science Board, *Science and Engineering Indicators: 1996* (Washington, D.C.: U.S. Government Printing Office, 1996).

Royalties and Fees

Japan has traditionally been a net importer of technological know-how. In 1990, Japan paid over $7 billion in royalties and fees for access to intellectual property from other countries, more than twice as much as it sold to other countries. The United States has traditionally been a net exporter of intellectual property, maintaining a large surplus in international trade of technical knowledge. In 1990, the United States had more than a 3-to-1 ratio of receipts (exports) to payments (imports) for intellectual property. The surplus of receipts (sales of technical know-how) over payments (purchases) may indicate that the United States is strong in the creation of industrial technology (table A-26).

The amount of U.S. receipts of royalties and license fees generated from the exchange of industrial processes differs by country. Compared with the other major industrialized countries, Japan has the highest ratio of payments-to-receipts for access to U.S. technology. In 1993, U.S. companies received 7 times more than they paid in the exchange of technical know-how with Japanese firms (table 14).

However, when data from Japanese manufacturing industries are examined, a somewhat different picture emerges. In selected industries, Japanese companies are net exporters of technical know-how to the rest of the world. Data for 1990 show Japanese manufacturing industries' trade in technological know-how nearly in balance in 1990, and by 1993, Japanese companies received more in royalties and fees than they paid for technical know-how in several industry fields, including industrial chemicals, ceramics, iron and steel, and fabricated metals. Additionally, in motor vehicles the ratio of receipts-to-payments was 14-to-1, reflecting the spread of Japanese know-how in auto manufacturing in Europe and Asia (table A-27).

Trade in Advanced Technology Products

R&D and technological innovation play a major role in trade performance, particularly in advanced technology products.[25] The United States is the leading exporter of advanced technology products throughout the world, but has a large trade imbalance with Japan in these products. In 1992, the overall U.S. share of the world's exports of advanced technologies to all countries was about 25 percent, compared with Japan's share of 17 percent (table 15). The U.S. share of the world's exports is particularly large in biotechnology fields, aerospace industries, and weapons technologies, accounting for more than one-third of the world exports in these fields; Japan is particularly strong in information technologies and electronics, accounting for about one-quarter of the world exports in these fields.

[25] The list of advanced technology products is compiled by the U.S. Bureau of the Census. To be included in one of the categories, a product must contain a significant amount of one of the leading-edge technologies, and the technology must account for a significant portion of the product's value.

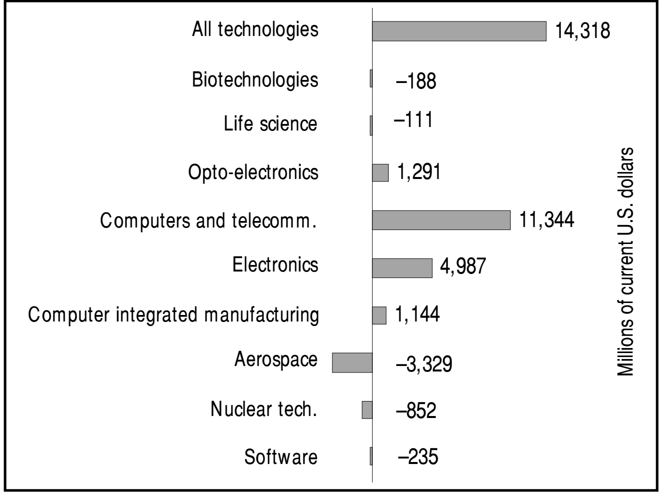
Table 15. Share of world exports of advanced technology products: 1992

Technology	United States	Japan
	[Percent]	
All technologies	25.2%	17.0%
Biotechnologies	37.0	4.3
Life science technologies	27.5	13.8
Opto-electronics	13.7	22.8
Information technologies	18.5	23.0
Electronics	20.3	25.5
Manufacturing technologies	16.2	21.5
Advanced materials	28.6	9.3
Aerospace	44.2	1.4
Weapons technologies	34.3	4.6
Nuclear technologies	20.8	0.2

NOTE: Technologies represent broader categories than the standard classification of industries.

SOURCE: DRI/McGraw Hill, special tabulations, April, 1994, as presented in *Science and Engineering Indicators: 1996.*

Figure 31. Japanese trade balance with the United States in advanced technology products: 1994



NOTE: Currency conversion uses official exchange rate.

See appendix table A-28.

However, in considering only U.S.–Japan bilateral trade (rather than world-wide trade), in 1994 Japan's export of advanced technology products reached more than $28 billion, exceeding imports from the United States by more than $14 billion and indicating that Japan is also strong in the creation of such industrial output. The largest trade surpluses for Japan are from computers and telecommunications and electronics. The largest deficits for Japan from high technology trade with the United States result from aerospace and nuclear technology, and increasingly from software (figure 31).